# Optical Short Course International

6679 N. Calle de Calipso, Tucson, AZ www.oscintl.com 520-797-9744

## What's "Inside The Box"?

## Optics of Digital Projectors Weekly Newsletter

*Sponsored By:*



### *TIR Prisms in Digital Projector Illumination Systems*

By Michael Pate, President, OSCI

We have been looking at illumination system components and how they work in light engine illumination system designs. This week we will look illumination system again but at a specific component called a TIR prism. These prisms are very useful and elegant devices used to get light into and out of spatial light modulators. They are efficient in the use of valuable opto-mechanical real estate in digital projector light engines. They work on the principle of total internal reflection which is very efficient. They do require a complex optical element which is made from two prism halves and five polished and coated faces with three precision angles. More optical surfaces and bulk glass path thickness means that more scattering from surfaces and the bulk optical material and this decreases the inherent light engine contrast. These are some of the tradeoffs of using TIR Prisms in digital projector light engines. Lets take a closer look at these devices.

**What is a TIR Prism?**

TIR is the acronym for one of the key optical principles called Total Internal Reflection. When an electromagnetic wave or ray in our case encounter a surface with a different refractive index there will be refraction of the ray based upon Snell's Law.

$n Sin\theta = n' Sin\theta'$ *Where n is the refractive index and $\theta$ is the angle of incidence*

The unprimed quantities are before and the primed quantities are after refraction.

When the rays go from rare to dense media where n < n' the ray will almost always get into the surface, for example going from air to glass. The magnitude of the reflected or transmitted ray of course changes with angle and also depends upon the polarization especially at higher angles of incidence.

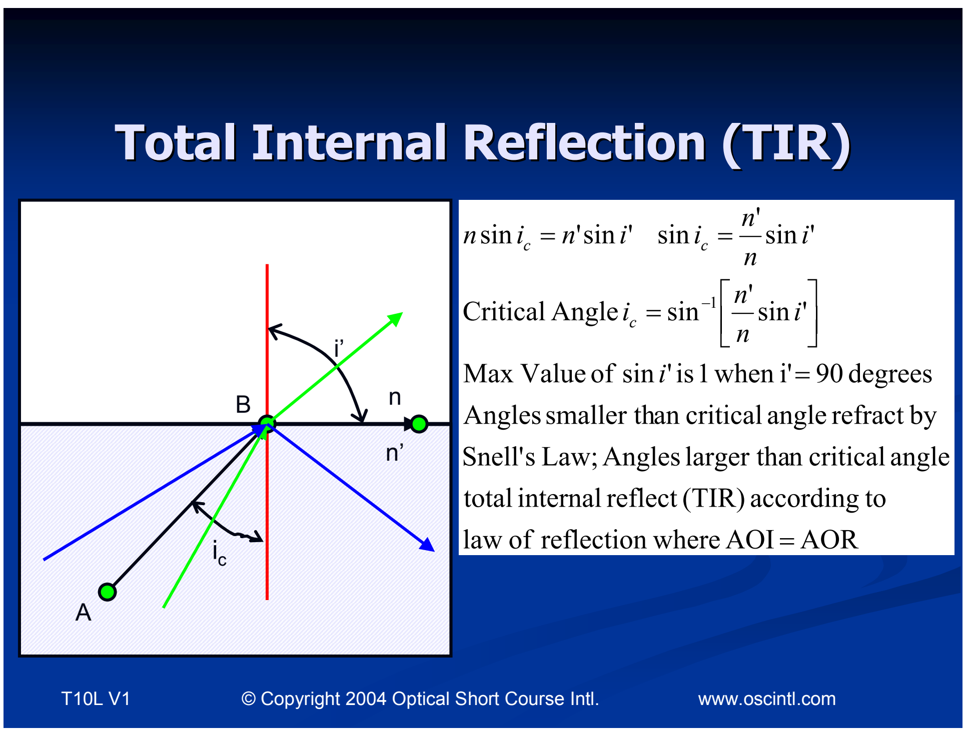


Figure 1. Total Internal Reflection
From OSCI DVD Course Top 10 Laws of Optics

You may recall that when an electromagnetic wave or ray in our case encounters an interface surface when going from dense to rare index of refraction where n' > n the ray will refract out of the dense material up to a certain angle. This angle is called the critical angle and is where the refracted angle is equal to 90 degrees. Angle of incidence above or greater than the critical angle will be 100% reflected from the surface and will obey the law of reflection. For more information about these laws see our DVD course Top 10 Laws of Optics.

In digital projector light engines there are two main types of prisms that work on the TIR principle and they are the TIR Prism and the Philips Prism. We will take a look at both of these prisms. The TIR Prism is most often used in single panel light engines using the TI DMD and is shown below in Figures 2 & 3.

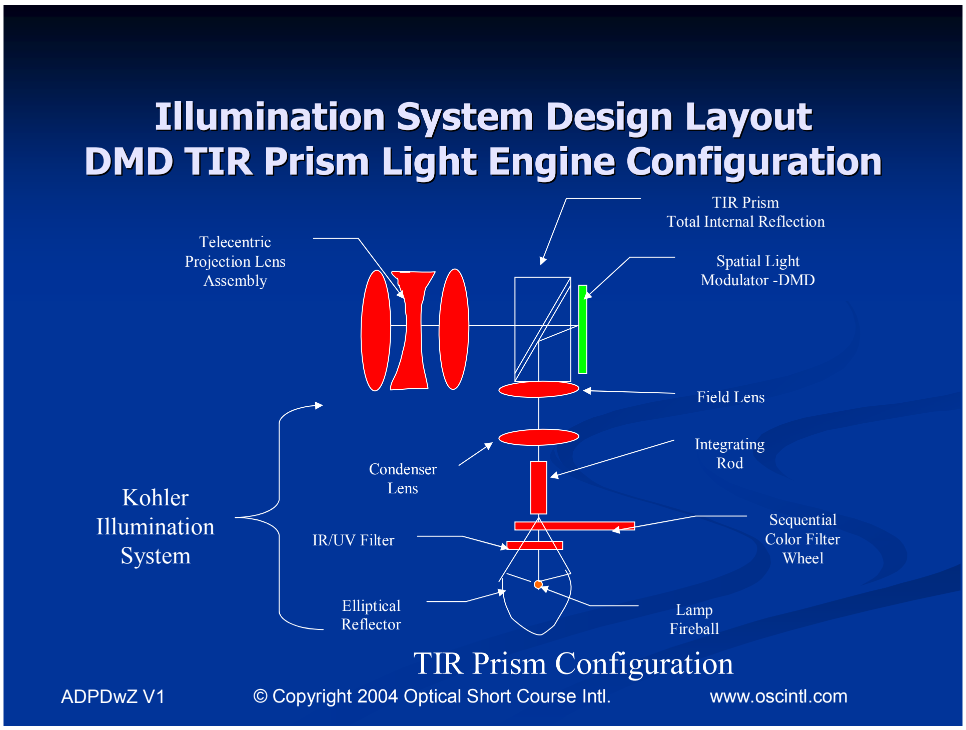


Figure 2. TIR Light Engine Layout
From OSCI Course Applied Digital Projector Design with Zemax

In Figure 2 we can see the illumination from the bulb, integrating rod, and condenser and field lens is incident through the modulator part of the prism. The light from the illumination system will TIR off of the hypotenuse part of the TIR Prism and exit the prism and illuminate the spatial light modulator or DMD. To the projection lens assembly the TIR prism just looks like a plane parallel plate of glass. The light that reflects from DMD pixels that are turned on, will pass through the hypotenuse because the angle of incidence is smaller than the critical angle.

In Figure 3 below we have zoomed in to investigate the properties of the modulator part of the TIR prism. We can see that the light from the illumination system may or may not be refracted as it enters the prism and propagates towards the hypotenuse. All of the light which has an angle of incidence greater than the critical angle of the prism will be reflected by total internal reflection. This light exits the modulator face and refracts at the exit face of the prism. This light next interacts with the modulator and if reflected from the modulator it typically comes back through the modulator face propagating towards the hypotenuse. At the hypotenuse this light has an angle of incidence which is less than the critical angle so it will transmit through the face rather than TIR. This light then encounters the air gap between the two TIR prism halves and enters the projection lens prism and propagates toward the projection lens assembly and finally onto the screen for your viewing pleasure.

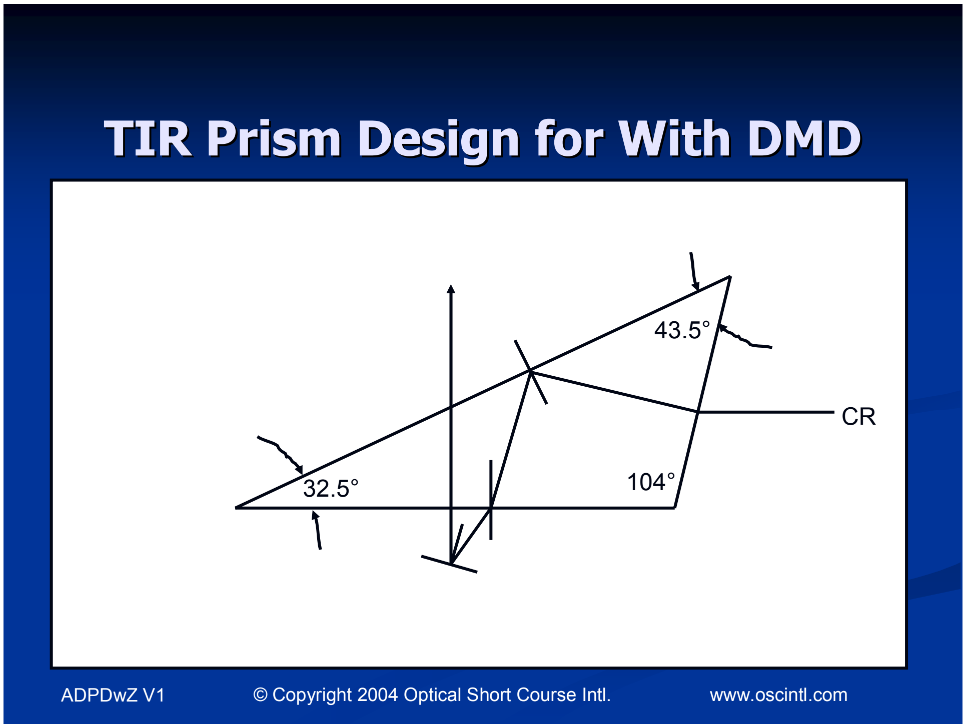


Figure 3. Lower Prism Layout and Angles
From OSCI Course Applied Digital Projector Design with Zemax

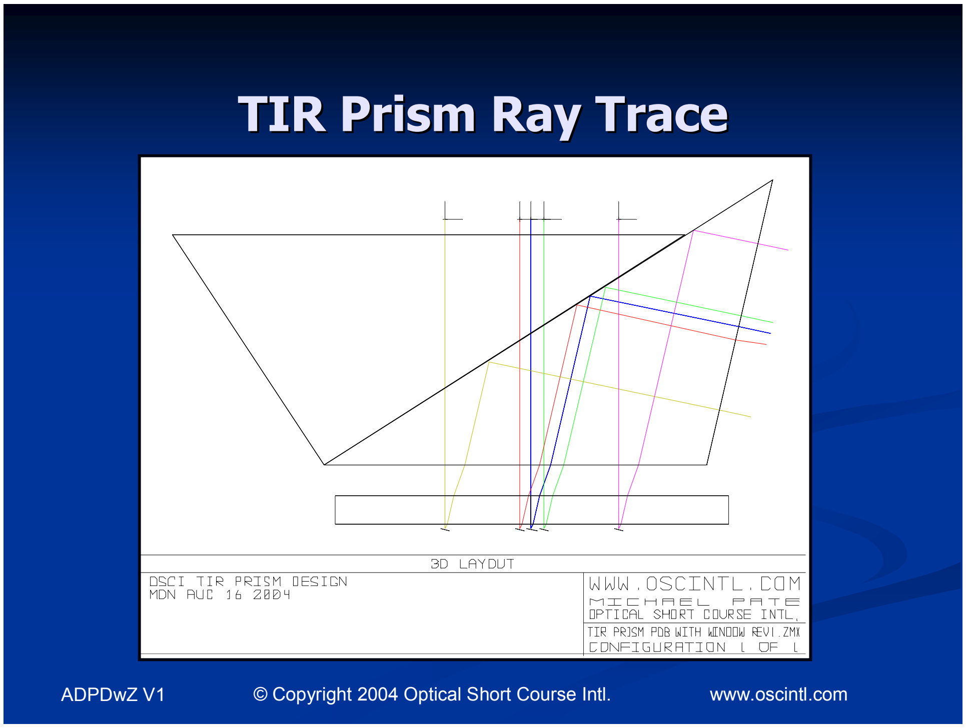


Figure 4. Full Prism Ray Trace
From OSCI Course Applied Digital Projector Design with Zemax

In Figure 5 below we can see another prism that is based upon the TIR concept and this prism is used in three panel digital projector light engines. This prism has its history in early color television cameras and is called a Philips prism. You can see a TIR prism sitting on top of this configuration and it folds the white or broadband light into the lower parts of the prism assembly. For our discussion here the bottom of prisms will be on the left and the top on the right.

The white light enters the top of the blue prism and is chromatically split at the bottom of the blue prism by a dichroic thin film filter. The blue is reflected and the red and green continue. The blue is reflected back toward the top of the blue prism where it TIR's and interacts with the blue modulator. If the pixels are turned on this light is reflected back towards the top of the blue prism and TIR's again and heads toward the bottom surface again. This blue light reflects off of the dichroic filter again and heads out of the prism assemblies towards the projection lens assembly.

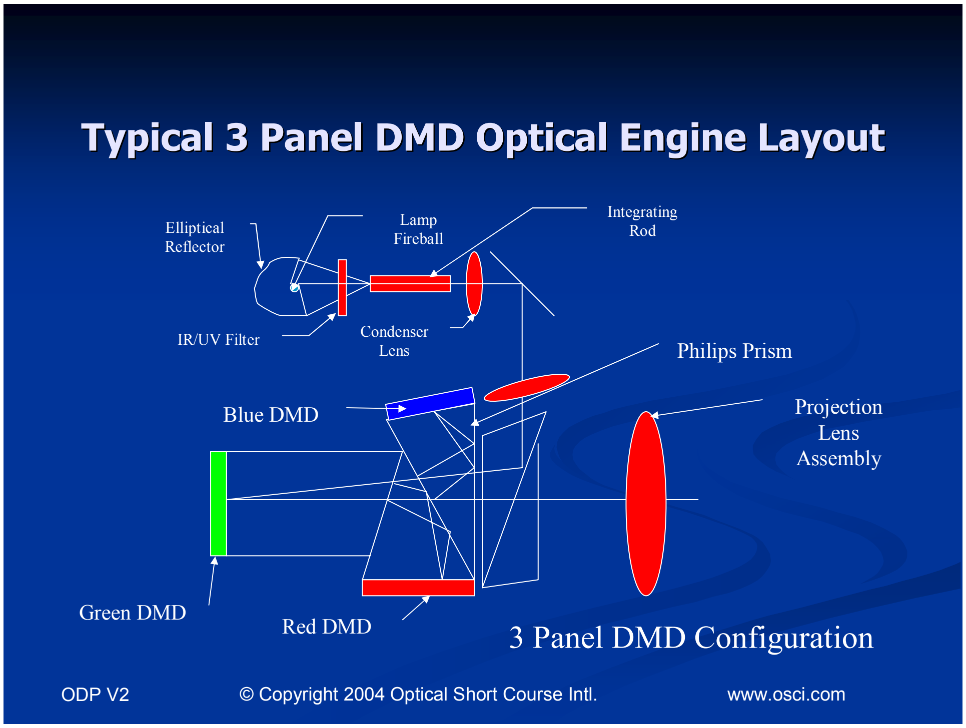


Figure 5. 3 Panel Light Engine with Philips TIR Prism
From OSCI Course Applied Digital Projector Design with Zemax

The red and green light enter the top of the red prism and get separated at the bottom of the red prism by another dichroic filter. The red is reflected and the green passes through the surface. The red light that was reflected from the bottom of the red prism TIR's off of the top of the red prism and interacts with the red modulator. If the pixels are turned on this light is reflected back towards the top of the red prism and TIR's again and heads toward the bottom surface again. This red light reflects off of the dichroic filter again and heads out of the prism assemblies towards the projection lens assembly.

The green light simply interacts with the green modulator and if turned on it reflects out toward the projection lens assembly passing back through all of the prism dichroic filters and TIR surfaces.

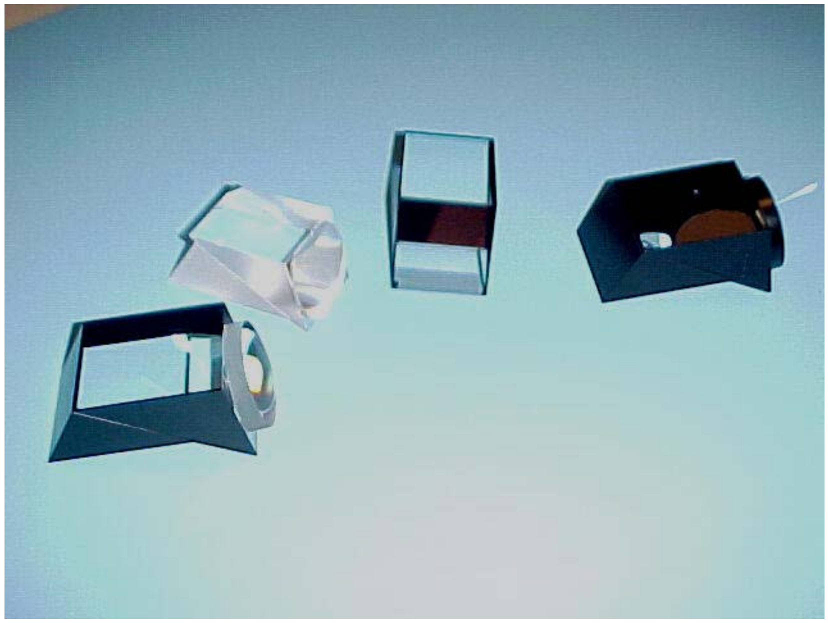

Figure 6. TIR Prisms
Courtesy of Unaxis Optics

**Summary**
We have taken a look at two different types of prisms that use the principle of total internal reflection to direct the light from an illumination and imaging system where we want it to be delivered. The first is the TIR Prism used in single panel digital projector light engines. The second is the Philips Prism used in three panel digital projector light engines. The TIR Prism is an elegant device for plumbing light into and out of a spatial light modulator like the DMD from Texas Instruments. The TIR Prism is often used to conserve precious space in an opto-mechanical assembly but there are cost and contrast tradeoffs to be considered.

Next week we will take a look at some more illumination components like molded aspheric optics. So stay tuned and keep looking for your weekly dose of "In The Box" to understand the optics of digital projectors. If you enjoy increasing your knowledge about digital projector optics please tell a friend about this e-newletter, your referral is the kindest compliment we can get to show your appreciation.